CLAIMS

I/We claim:

1. An instrument for stimulating and/or sensing neurons in the nervous system of a patient, comprising:

a body configured to be implanted into a patient;

an electrode contact carried by the body and an electrically conductive line coupled to the electrode contact; and

a marker carried by the body, the marker having a transponder configured to be energized by a wirelessly transmitted excitation energy and to wirelessly transmit a location signal in response to the excitation energy.

2. The instrument of claim 1 wherein the body comprises a shaft configured to be implanted into a subdural region of the brain of the patient, and the electrode contact comprises an electrically conductive member exposed along a portion of the shaft.

3. The instrument of claim 2 wherein the electrode contact comprises a band around a portion of the shaft.

4. The instrument of claim 1 further comprising a plurality of electrode contacts including a first electrode contact at a first location on the body and a second electrode contact at a second location on the body spaced apart from the first location.

5. The instrument of claim 1 wherein the body comprises a shaft having a distal section configured to be implanted at a subdural location in the brain of the patient, and wherein the instrument further comprises a plurality of electrode contacts including a first electrode contact at a first location on the distal section of the body and a second electrode contact at a second location on the distal section of the body spaced apart from the first location.

6. The instrument of claim 5 wherein the first and second electrode contacts are coupled to a common lead to be biased at the same potential.

7. The instrument of claim 5 wherein the first electrode contact is coupled to a first lead and the second electrode contact is coupled to a second lead such that first and second electrode contacts can be biased at different potentials.

8. The instrument of claim 1 wherein the transponder comprises an alternating magnetic circuit having a ferrite core and a coil with a plurality of windings around the ferrite core.

9. The instrument of claim 1 wherein the transponder comprises a ferrite core and a coil around the ferrite core, and wherein the marker further comprises a capsule encasing the transponder, the capsule having a longitudinal axis and a cross-sectional dimension normal to the longitudinal axis of not greater than 2 mm.

10. The instrument of claim 1 wherein the marker comprises a capsule and the transponder comprises an alternating magnetic circuit within the capsule, and wherein the transponder is not electrically coupled to external leads outside of the capsule.

11. The instrument of claim 1 wherein the marker comprises a capsule and an alternating magnetic circuit in the capsule, and wherein the marker has a radiographic centroid and the alternating magnetic circuit has a magnetic centroid at least approximately coincident with the radiographic centroid.

12. The instrument of claim 1 wherein the marker comprises an alternating magnetic circuit having a ferrite core, a coil having a plurality of windings around the core, and an imaging element, and wherein the marker has a radiographic centroid and the alternating magnetic circuit has a magnetic centroid at least approximately coincident with the radiographic centroid.

13. The instrument of claim 1 wherein the marker comprises an alternating magnetic circuit having a ferrite core extending along a longitudinal axis, a coil having a plurality of windings around the core, and a capsule encasing the core and the coil, and wherein the core has a maximum cross-sectional dimension normal to the longitudinal axis of not greater than 0.7 mm and the capsule has a maximum cross-sectional dimension normal to the longitudinal axis of not greater than 2 mm.

14. The instrument of claim 1, further comprising a drug delivery element along the body.

15. An instrument for stimulating and/or sensing neurons in the nervous system of a patient, comprising:

an elongated shaft configured to be implanted into a patient;

an electrode contact carried by the shaft and an electrically conductive line coupled to the electrode contact; and

a marker attached to the shaft, the marker having an alternating magnetic circuit configured to be energized by a wirelessly transmitted pulsed magnetic excitation field and to wirelessly transmit a pulsed magnetic location signal in response to the magnetic excitation field.

16. The instrument of claim 15 wherein the marker comprises a capsule encasing the alternating magnetic circuit, and wherein the marker has a radiographic centroid and the alternating magnetic circuit has a magnetic centroid at least approximately coincident with the radiographic centroid.

17. The instrument of claim 15 wherein the alternating magnetic circuit comprises a ferrite core, a coil having a plurality of windings around the core, and an imaging element, and wherein the marker has a radiographic centroid and the alternating magnetic circuit has a magnetic centroid at least approximately coincident with the radiographic centroid.

18. The instrument of claim 15 wherein the alternating magnetic circuit comprises a ferrite core extending along a longitudinal axis, a coil having a plurality

of windings around the core, and a capsule encasing the core and the coil, and wherein the core has a maximum cross-sectional dimension normal to the longitudinal axis of not greater than 0.7 mm and the capsule has a maximum cross-sectional dimension normal to the longitudinal axis of not greater than 2 mm.

19. An electrode for subdural sensing and/or stimulation in a brain of a patient, comprising:

an elongated body having a distal section configured to be implanted at a subdural location in the brain of the patient and a proximal section;

a lead connector at the proximal section of the body;

an electrode contact on the distal section of the body;

an electrical conductor coupled to the electrode contact and the lead connector; and

a marker carried by the body at a fixed location with respect to the electrode contact, the marker comprising an alternating magnetic transponder configured to be energized by a wirelessly transmitted excitation energy and produce a wirelessly transmitted location signal in response to the excitation energy.

20. The electrode of claim 19 wherein the marker comprises a capsule encasing the alternating magnetic transponder, and wherein the marker has a radiographic centroid and the alternating magnetic transponder has a magnetic centroid at least approximately coincident with the radiographic centroid.

21. The electrode of claim 19 wherein the alternating magnetic transponder comprises a ferrite core, a coil having a plurality of windings around the core, and an imaging element, and wherein the marker has a radiographic centroid and the alternating transponder has a magnetic centroid at least approximately coincident with the radiographic centroid.

22. The electrode of claim 19 wherein the alternating magnetic transponder comprises a ferrite core extending along a longitudinal axis, a coil having a plurality of windings around the core, and a capsule encasing the core and

the coil, and wherein the core has a maximum cross-sectional dimension normal to the longitudinal axis of not greater than 0.7 mm and the capsule has a maximum cross-sectional dimension normal to the longitudinal axis of not greater than 2 mm.

23. A stimulation system, comprising:

an implantable stimulus unit having an energy source and a pulse generator coupled to the energy source for providing an electrical stimulation waveform;

a stimulation lead configured to be coupled to the implantable stimulus unit, the simulation lead having a flexible dielectric cover and a conductor within the cover, and the simulation lead being configured to be implanted within the patient; and

an instrument having a body configured to be implanted into a patient, an electrode contact carried by the body and configured to be electrically coupled to the stimulation lead for delivering the stimulation waveform to the patient, and a marker carried by the body, wherein the marker comprises a transponder configured to be energized by a wirelessly transmitted excitation energy and to wirelessly transmit a location signal in response to the excitation energy.

24. The system of claim 23 wherein the body comprises a shaft configured to be implanted into a subdural region of the brain of the patient, and the electrode contact comprises an electrically conductive member exposed along a portion of the shaft.

25. The system of claim 24 wherein the electrode contact comprises a band around a portion of the shaft.

26. The system of claim 23 further comprising a plurality of electrode contacts on the body, the electrode contacts including a first electrode contact at a first location on the body and a second electrode contact at a second location on the body spaced apart from the first location.

27. The system of claim 23 wherein the body comprises a shaft having a distal section configured to be implanted at a subdural location in the brain of the patient, and wherein the instrument further comprises a plurality of electrode contacts including a first electrode contact at a first location on the distal section of the body and a second electrode contact at a second location on the distal section of the body spaced apart from the first location.

28. The system of claim 27 wherein the first and second electrode contacts are coupled to a common lead to be biased at the same potential.

29. The system of claim 27 wherein the first electrode contact is coupled to a first lead and the second electrode contact is coupled to a second lead such that first and second electrode contacts can be biased at different potentials.

30. The system of claim 23 wherein the transponder comprises an alternating magnetic circuit having a ferrite core and a coil with a plurality of windings around the ferrite core.

31. The system of claim 23 wherein the transponder comprises a ferrite core and a coil around the ferrite core, and wherein the marker further comprises a capsule encasing the transponder, the capsule having a longitudinal axis and a cross-sectional dimension normal to the longitudinal axis of not greater than 2 mm.

32. The system of claim 23 wherein the marker comprises a capsule and the transponder comprises an alternating magnetic circuit within the capsule, and wherein the transponder is not electrically coupled to external leads outside of the capsule.

33. The system of claim 23 wherein the marker comprises a capsule and an alternating magnetic circuit in the capsule, and wherein the marker has a radiographic centroid and the alternating magnetic circuit has a magnetic centroid at least approximately coincident with the radiographic centroid.

34. The system of claim 23 wherein the marker comprises an alternating magnetic circuit having a ferrite core, a coil having a plurality of windings around the core, and an imaging element, and wherein the marker has a radiographic centroid and the alternating magnetic circuit has a magnetic centroid at least approximately coincident with the radiographic centroid.

35. The system of claim 23 wherein the marker comprises an alternating magnetic circuit having a ferrite core extending along a longitudinal axis, a coil having a plurality of windings around the core, and a capsule encasing the core and the coil, and wherein the core has a maximum cross-sectional dimension normal to the longitudinal axis of not greater than 0.7 mm and the capsule has a maximum cross-sectional dimension normal to the longitudinal axis of not greater than 2 mm.

36. The system of claim 23 wherein the instrument further comprises a drug delivery element along the body.

37. A stimulation system, comprising:

an implantable stimulus unit having an energy source and a pulse generator coupled to the energy source for providing an electrical stimulation waveform;

a stimulation lead configured to be coupled to the implantable stimulus unit, the simulation lead having a flexible dielectric cover and a conductor within the cover, and the simulation lead being configured to be implanted within the patient; and

an instrument having an elongated body including a distal section configured to be implanted at a subdural location in the brain of the patient and a proximal section configured to be connected to the stimulation lead, an electrode contact on the distal section of the body for delivering the stimulation waveform to the patient, and a marker carried by the body at a fixed location with respect to the electrode contact, the marker comprising a leadless alternating magnetic transponder configured to be energized by a wirelessly transmitted excitation energy and to

wirelessly transmit a location signal in response to the excitation energy.

38. A system for sensing and/or stimulating a population neurons in the central nervous system of a patient, comprising:

an instrument having a body configured to be implanted into a patient, an electrode contact carried by the body, and a marker carried by the body, wherein the marker comprises a transponder having a circuit configured to be energized by a wirelessly transmitted pulsed magnetic excitation field and to wirelessly transmit a pulsed location signal in response to the pulsed magnetic excitation field; and

an excitation source comprising an energy storage device, a source coil, and a switching network coupled to the energy storage device and the source coil, the source coil being configured to wirelessly transmit the pulsed magnetic excitation field to energize the transponder, and the switching network being configured to alternately transfer (a) stored energy from the energy storage device to the source coil and (b) energy in the source coil back to the energy storage device.

39. The system of claim 38 wherein the switching network comprises an H-bridge switch.

40. The system of claim 38 wherein the switching network is configured to have a first on position in which the stored energy is transferred from the energy storage device to the source coil and a second on position in which energy in the source coil is transferred back to the energy storage device.

41. The system of claim 40 wherein the first on position has a first polarity and the second on position has a second polarity opposite the first polarity.

42. The system of claim 38 wherein the source coil comprises an array having a plurality of substantially coplanar coils.

43. The system of claim 42 wherein the switching network is configured to selectively energized the coplanar coils to change a spatial configuration of the pulsed magnetic field.

44. The system of claim 38 wherein the body comprises a shaft configured to be implanted into a subdural region of the brain of the patient, and the electrode contact comprises an electrically conductive member exposed along a portion of the shaft.

45. The system of claim 38 wherein the electrode contact comprises a band around a portion of the shaft.

46. The system of claim 38 further comprising a plurality of electrode contacts on the body, the electrode contacts including a first electrode contact at a first location on the body and a second electrode contact at a second location on the body spaced apart from the first location.

47. The system of claim 38 wherein the body comprises a shaft having a distal section configured to be implanted at a subdural location in the brain of the patient, and wherein the instrument further comprises a plurality of electrode contacts including a first electrode contact at a first location on the distal section of the body and a second electrode contact at a second location on the distal section of the body spaced apart from the first location.

48. The system of claim 38 wherein the first and second electrode contacts are coupled to a common lead to be biased at the same potential.

49. The system of claim 38 wherein the first electrode contact is coupled to a first lead and the second electrode contact is coupled to a second lead such that first and second electrode contacts can be biased at different potentials.

50. The system of claim 38 wherein the circuit comprises an alternating magnetic circuit having a ferrite core and a coil with a plurality of windings around the ferrite core.

51. The system of claim 38 wherein the circuit comprises a ferrite core and a coil around the ferrite core, and wherein the marker further comprises a capsule encasing the transponder, the capsule having a longitudinal axis and a cross-sectional dimension normal to the longitudinal axis of not greater than 2 mm.

52. The system of claim 38 wherein the marker comprises a capsule and the circuit comprises an alternating magnetic circuit within the capsule, and wherein the transponder is not electrically coupled to external leads outside of the capsule.

53. The system of claim 38 wherein the marker comprises a capsule and the circuit is in the capsule, and wherein the marker has a radiographic centroid and the alternating magnetic circuit has a magnetic centroid at least approximately coincident with the radiographic centroid.

54. The system of claim 38 wherein the circuit comprises an alternating magnetic circuit having a ferrite core, a coil having a plurality of windings around the core, and an imaging element, and wherein the marker has a radiographic centroid and the alternating magnetic circuit has a magnetic centroid at least approximately coincident with the radiographic centroid.

55. The system of claim 38 wherein the circuit comprises an alternating magnetic circuit having a ferrite core extending along a longitudinal axis, a coil having a plurality of windings around the core, and a capsule encasing the core and the coil, and wherein the core has a maximum cross-sectional dimension normal to the longitudinal axis of not greater than 0.7 mm and the capsule has a maximum cross-sectional dimension normal to the longitudinal axis of not greater than 2 mm.

56. The system of claim 38 wherein the instrument further comprises a drug delivery element along the body.

57. A system for sensing and/or stimulating a population neurons in the central nervous system of a patient, comprising:

an instrument having a body configured to be implanted into a patient, an electrode contact carried by the body, and a marker carried by the body, wherein the marker comprises a transponder having a circuit configured to be energized by a wirelessly transmitted pulsed excitation field and to wirelessly transmit a pulsed location signal in response to the pulsed excitation field; and

a sensing assembly comprising a support member and a plurality of field sensors carried by the support member, the field sensors being at least substantially locally planar relative to one another and configured to sense the pulsed location signal from the marker.

58. The system of claim 57 wherein the field sensors are responsive only to field components of the location signal normal to individual field sensors.

59. The system of claim 57 wherein the field sensors are arranged in an array occupying an area having a maximum dimension of approximately 100% to 300% of a predetermined sensing distance between the marker and the sensing array.

60. The system of claim 57 wherein the body comprises a shaft configured to be implanted into a subdural region of the brain of the patient, and the electrode contact comprises an electrically conductive member exposed along a portion of the shaft.

61. The system of claim 57 further comprising a plurality of electrode contacts on the body, the electrode contacts including a first electrode contact at a first location on the body and a second electrode contact at a second location on the body spaced apart from the first location.

62. The system of claim 57 wherein the first and second electrode contacts are coupled to a common lead to be biased at the same potential.

63. The system of claim 57 wherein the first electrode contact is coupled to a first lead and the second electrode contact is coupled to a second lead such that first and second electrode contacts can be biased at different potentials.

64. The system of claim 57 wherein the circuit comprises an alternating magnetic circuit having a ferrite core and a coil with a plurality of windings around the ferrite core.

65. The system of claim 57 wherein the circuit comprises a ferrite core and a coil around the ferrite core, and wherein the marker further comprises a capsule encasing the transponder, the capsule having a longitudinal axis and a cross-sectional dimension normal to the longitudinal axis of not greater than 2 mm.

66. The system of claim 57 wherein the marker comprises a capsule and the circuit comprises an alternating magnetic circuit within the capsule, and wherein the transponder is not electrically coupled to external leads outside of the capsule.

67. The system of claim 57 wherein the marker comprises a capsule and the circuit is in the capsule, and wherein the marker has a radiographic centroid and the alternating magnetic circuit has a magnetic centroid at least approximately coincident with the radiographic centroid.

68. The system of claim 57 wherein the circuit comprises an alternating magnetic circuit having a ferrite core, a coil having a plurality of windings around the core, and an imaging element, and wherein the marker has a radiographic centroid and the alternating magnetic circuit has a magnetic centroid at least approximately coincident with the radiographic centroid.

69. The system of claim 57 wherein the circuit comprises an alternating magnetic circuit having a ferrite core extending along a longitudinal axis, a coil having a plurality of windings around the core, and a capsule encasing the core and the coil, and wherein the core has a maximum cross-sectional dimension normal to

the longitudinal axis of not greater than 0.7 mm and the capsule has a maximum cross-sectional dimension normal to the longitudinal axis of not greater than 2 mm.

70. The system of claim 57 wherein the instrument further comprises a drug delivery element along the body.

71. A method of implanting an instrument used for sensing and/or stimulating a population of neurons at a selected stimulation site in a patient, comprising:

inserting into the patient an instrument having an electrode contact and a marker including a transponder; and

tracking the instrument in a reference volume when the instrument is in the patient by (a) wirelessly delivering a pulsed excitation signal to energize the transponder, (b) wirelessly transmitting a pulsed location signal from the transponder to a location outside of the patient, (c) sensing the pulsed location signal at a sensor located outside of the patient, and (d) calculating the location of the marker in the three-dimensional reference volume.

72. The method of claim 71 wherein inserting the instrument into the patient comprises moving the instrument through the brain to a deep brain location, and tracking the instrument comprises periodically calculating the location of the marker in the reference volume while moving the instrument through the brain.

73. The method of claim 71 wherein inserting the instrument into the patient comprises moving the instrument through the brain to a deep brain location, and tracking the instrument comprises (a) periodically calculating a location of the marker in the reference volume while moving the instrument through the brain, and (b) periodically determining a relative offset between the electrode contact and the stimulation site based on the periodically calculated locations of the marker.

74. The method of claim 73, further comprising displaying the relative offset between the electrode contact and the stimulation site.

75. The method of claim 73, further comprising terminating movement of the instrument when the relative offset between the electrode contact and the stimulation site is within a desired range.

76. The method of claim 73, further comprising providing an indication of when the relative offset between the electrode contact and the stimulation site is within an acceptable range.

77. A method for tracking an instrument used for sensing and/or stimulating a population of neurons at a selected stimulation site in a patient, comprising:

implanting an instrument into the patient, the instrument having an electrode contact and a marker including a transponder;

tracking the instrument with respect to the stimulation site by (a) wirelessly delivering a pulsed excitation signal to energize the transponder, (b) wirelessly transmitting a location signal from the transponder to a location outside of the patient, (c) sensing the pulsed location signal at a sensor located outside of the patient, and (d) periodically calculating the location of the marker in a reference volume; and

providing an output of the location of the marker in the reference volume at least every t_f seconds and within t_l seconds from sensing the location signal, wherein t_f and t_l are not greater than 1 second.

78. The method of claim 77 wherein tf and tl are from approximately 10 ms to approximate 500 ms

79. The method of claim 77 wherein tf and tl are from approximately 20 ms to approximate 200 ms

80. The method of claim 77 wherein tf and tl are from approximately 50 ms to approximate 200 ms

81. The method of claim 77 wherein tf and tl are from approximately 50 ms to approximate 100 ms

82. The method of claim 77 wherein implanting the instrument into the patient comprises moving the instrument through the brain to a deep brain location, and tracking the instrument comprises periodically calculating the location of the marker in the reference volume while moving the instrument through the brain.

83. The method of claim 77 wherein implanting the instrument into the patient comprises moving the instrument through the brain to a deep brain location, tracking the instrument comprises periodically calculating the location of the marker in the reference volume while moving the instrument through the brain, and providing an output of the location of the marker comprises providing a relative offset between the electrode contact and the stimulation site based on the periodically calculated locations of the marker.

84. The method of claim 83, further comprising displaying the relative offset between the electrode contact and the stimulation site.

85. The method of claim 83, further comprising terminating movement of the instrument when the relative offset between the electrode contact and the stimulation site is within a desired range.

86. The method of claim 83, further comprising providing an indication of when the relative offset between the electrode contact and the stimulation site is within an acceptable range.

87. A method for implanting an instrument for sensing and/or stimulating a population of neurons at a selected stimulation site in a patient, comprising:

implanting into the patient an instrument having an electrode contact and a marker including a transponder;

determining the location of the instrument in a reference volume by (a) wirelessly delivering a pulsed excitation signal to energize the

transponder, (b) wirelessly transmitting a pulsed location signal from the transponder to a location outside of the patient, (c) sensing the pulsed location signal at a sensor located outside of the patient, and (d) calculating the location of the marker in a three-dimensional reference volume; and

receiving electrical signals at the electrode contact from the population of neurons and/or delivering electrical stimulation from the electrode contact.